AD-A094 618 PRINCETON UNIV NJ DEPT OF MECHANICAL AND AEROSPACE --ETC F/G 21/9.2
SOLID PROPELLANT COMBUSTION MECHANISM RESEARCH 1975-1980.(U)
APR 80 L H CAVENY, M SUMMERFIELD, J BELLAN N00014-75-C-0705
UNCLASSIFIED MAE-1490 NL

1 OF 1
AD-
A094618

END
DATE
FILMED
3-81
DTIC

AD A094618

LEVEL II

(3)

SOLID PROPELLANT COMBUSTION MECHANISM RESEARCH

1975-1980 FINAL REPORT TO THE OFFICE OF NAVAL RESEARCH

By

Leonard H. Caveny, Martin Summerfield,
Josette Bellan and Moshe BenReuven

Performed under Office of Naval Research
Contract N00014-75-C-0705

Partial support provided by
U. S. Army Ballistic Research Laboratory

Submitted by

Leonard H. Caveny

April 1980

MAE REPORT NO. 1490

Department of Mechanical and Aerospace Engineering
PRINCETON UNIVERSITY
Princeton, New Jersey 08544

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO. AD-A094 618	3. RECIPIENT'S CATALOG NUMBER (9)
4. TITLE (and Subtitle) (6) SOLID PROPELLANT COMBUSTION MECHANISM RESEARCH 1975-1980. ~~FINAL REPORT~~		5. TYPE OF REPORT & PERIOD COVERED Final 1 Apr [redacted] 75-31 Mar [redacted] 80
		6. PERFORMING ORG. REPORT NUMBER (14) MAE [redacted] 1490
7. AUTHOR(s) (10) Leonard H. Caveny, Martin Summerfield, Josette Bellan ~~and~~ Moshe BenReuven		8. CONTRACT OR GRANT NUMBER(s) (15) N00014-75-C-0705
9. PERFORMING ORGANIZATION NAME AND ADDRESS Dept. of Mechanical & Aerospace Engineering, Princeton University, Princeton, NJ 08544		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS (12) 22
11. CONTROLLING OFFICE NAME AND ADDRESS Power Branch, Office of Naval Research, Washington, DC (11)		12. REPORT DATE April 1980
		13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report)
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Partial support provided by U. S. Army Ballistic Research Laboratory.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Solid Propellant Combustion	Acoustic Admittance	Nitramines
Droplet Combustion	Nonsteady burning	Combustion instability
Droplet extinction	Combustion stability	
Erosive burning	HMX	
Laser Doppler Velocimetry	RDX	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The multi-task research conducted during the five years of the contract was aimed at furthering the scientific understanding of propellant combustion processes. The low pressure deflagrations of nitramines were interpreted by a physical model that accounts for the interactions among the condensed phase, surface, and near field flame zones. The model demonstrated the importance of considering both primary and secondary gas phase processes. Chamber flow interactions with propellants having extended flame zones elucidated contributions to erosive burning and sustained acoustic oscillations. The analysis

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED 410 152

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

points to the existence of an additional source of acoustic energy produced by couplings with heat addition from residual reactions in the chamber gases. Droplet burning was analyzed in terms of a reduced boundary condition at the surface and the quasi-steady heat feedback assumption. A formalism is offered for experimentally evaluating the boundary conditions for nonsteady conditions. Direct measurements of solid propellant acoustic admittance were made using laser doppler velocimetry coupled with an optical technique for tracking the burning surface. This report contains abstracts of the detailed publications on each topic.

PREFACE

The research referred to in this final report was carried out under Contract N00014-75-C-0705 from the Power Branch, Office of Naval Research. Dr. Richard S. Miller, of the Power Branch, was the Program Manager. The U. S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD , provided partial support for this research. Mr. C. W. Nelson provided technical liaison with the Army.

APERÇU

The Office of Naval Research sponsorship of solid propellant research at Princeton University spanned more than two decades. Over the last year solid propellant and rocket research at Princeton University as a major activity was brought to an orderly end. All of the major contributors have elected to pursue their careers with other organizations. Several of us who have benefited from ONR sponsorship have reflected often on the many opportunities it provided. As we prepared the renewal proposals, we always felt the competition of our counterparts and the high standards set by ONR, but we were comfortable in the knowledge that a properly posed approach could be continued to its logical conclusion. Often approaches explored and found to be promising under ONR sponsorship were continued on a larger scale under other sponsorship. ONR funds were considered to be too valuable to be tied up on a single approach. The continuous nature of the funding was ideal for graduate student research which was usually planned for three years but often extended beyond that. Possibly the most important legacy of all this is the continuing contributions to propulsion and combustion by the faculty, staff, students, and visitors who were involved in the research.

TABLE OF CONTENTS

INTRODUCTION AND TECHNICAL OBJECTIVES

Research was performed on steady and unsteady combustion and reacting flow processes. The analytical and experimental approaches were motivated by broad scientific objectives. The immediate implications of the research are to greater understanding and new developments in solid propellant rocketry.

Investigations of items such as dynamic flame responses, high speed reacting flows, unsteady chamber flows, chemical kinetics, and mechanistic chemical interactions are conducted largely independently of each other. A continuing requirement exists for the investigators working in the various disciplines to interact and to give more attention to applying the results of research evolving from their areas of specialization. The physical measurements and mathematical models which were developed and refined as part of this endeavor provided many opportunities to use data and theories of other investigators. This was accomplished as data were acquired for validation of the models and for incorporation into the models. Also, chemical mechanisms proposed by others were evaluated by using the physical models in attempts to interpret observed phenomena.

During the period of the contract, four main topics were addressed:

1) Droplet burning
2) Nitramine monopropellant combustion
3) Interaction of chamber flow processes with propellant combustion
4) Direct measurement of acoustic admittance.

Abstracts of publications on each of these subjects are given in the next section.

ACCOMPLISHMENTS UNDER CONTRACT

Publications

Throughout the period of the contract, the research results were subjects of technical papers. Since the technical papers are distributed according to the CPIA mailing list as they become available, this report merely contains abstracts of the publications.

The publications summarized in the abstracts that follow are the papers which have been (or will be) archived by the appropriate libraries and agencies. Some types of publications (i.e., preprints of papers later published in journals, progress reports which were superseded by final reports, administrative summary reports which merely summarize other publications listed, and informal presentation summaries) have not been included if the results reported in them are also contained in a more comprehensive archive publication. It should be noted that the interplay among the publications is great since there has been a commonality of propellants, fuels, data reduction techniques, etc., throughout our investigations.

Abstracts of Publications

"FLAME ZONE AND SUB-SURFACE REACTION MODEL FOR DEFLAGRATING RDX"

M. BenReuven, L. H.Caveny, R. J. Vichnevetsky, and M. Summerfield

Proceedings of 16th Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, PA, 1976, pp. 1223-1233.

A study of 1,3,5 Trinitro Hexahydro 1,3,5, Triazine, RDX, burning as a monopropellant was undertaken to obtain a better understanding of the important chemical steps that control heat feedback to the condensed phase, to determine the contributions of the liquid layer, and to provide a means of evaluating theories for modifying the burning rate of nitramines. The following chemical mechanism is proposed: first, partial decomposition of RDX molecule in the liquid phase; second, following vaporization, gas phase decomposition of RDX; third, oxidation of formaldehyde by NO_2. The flame structure and liquid layer reactions of deflagrating RDX were expressed in terms of the energy, continuity, and species equations corresponding to RDX decomposing in liquid and gaseous phases and the NO_2/CH_2O reactions adjacent to the surface. In addition to the temperature profile and burning rate, the numerical solution provides the details of the interactions at the liquid/gas interface and the concentration profiles for the nine most prominent species. Using published kinetic data, the calculated results reveal that even though the liquid layer becomes thinner with increasing pressure, the increase in surface temperature causes its heat feedback contribution to increase. The pressure sensitivity of burning rate between 0.7 and 0.8 is interpreted in terms of the relative contributions of gas phase and liquid layer RDX decomposition and the oxidation of CH_2O. In particular, as pressure increases, the contribution from liquid layer reactions and the second order, NO_2/CH_2O reaction become more prominent.

Based on work performed under Contract N00014-75-C-0705 sponsored by the Power Branch of the Office of Naval Research.

"ON THE QUASI-STEADY ASSUMPTIONS FOR A BURNING DROPLET."

Josette Bellan and Martin Summerfield

AIAA Journal, Vol. 14, No. 7, July 1976, pp. 973-975.

A large number of results obtained in the field of droplet combustion are based upon the assumption that the gas field behaves in a quasi-steady manner. However, this assumption is introduced usually without adequate justification. Therefore, it is felt here that the discussion on the possibility of realistically making the quasi-steady assumption for the gas phase deserves particular attention. It was shown that for droplets in the range encountered in Diesel engines or rockets, there is a domain in the plane (τ_p,p) (τ_p is a characteristic time and p is a pressure) where the quasi-steady assumption is valid for typical pressures developed in the above combustion systems. As the droplet size decreases, the domain is shown to be larger.

Based on work performed under Contract N00014-75-C-0705 issued by the Power Branch of the Office of Naval Research.

Accession No. A76-39441. Available from AIAA.

A MODEL FOR STUDYING UNSTEADY DROPLET COMBUSTION

Josette Bellan and Martin Summerfield

AIAA Journal, Vol. 15, No. 2, February 1977, pp. 234-242.

The concept of a reduced boundary condition at the surface of a droplet is used to develop a new theory of unsteady droplet burning. This theory utilizes a quasi-steady gas phase assumption which has been shown to be realistic for a wide range of droplet sizes at low pressures. The most significant consequence of the theory is that the problem of unsteady droplet burning is reduced to the solving of a single diffusion-type nonlinear partial differential equation having one of its boundary conditions determined by an algebraic function of the quasi-steady gas phase variables. This reduced boundary condition incorporates the entire dependence of the solution on fuel characteristics, chemical kinetics and thermal properties of the gases. An experiment is proposed for determining this boundary condition so that the nonsteady droplet combustion problem can be solved for a realistic situation. By using additional assumptions, a numerical estimate of the boundary condition has been made.

Based on work performed under contract N00014-75-C-0705 sponsored by the Office of Naval Research.

Accession No. A76-38167 - available from AIAA. Accession number identifies AIAA Paper 76-614 which is superseded by above Journal article.

"THEORETICAL EXAMINATION OF ASSUMPTIONS COMMONLY USED FOR THE GAS PHASE SURROUNDING A BURNING DROPLET"

J. Bellan and M. Summerfield

Combustion and Flame, Vol. 33, No. 2, 1978, pp. 107-122

A finite reaction rate model is compared to three commonly used flame-sheet models. These three models differ in their treatment of the evaporation from the surface and the value used for the molecular weights. All four models are valid for both steady and unsteady burning of droplets. Further, they account for variations of droplet radii and allow for differences in ambient conditions. Numerical results (obtained for n-decane) show that if the radius of the droplet is 10^{-2} cm the thin flame approximation is excellent at 10 atm if the droplet surface temperature is not close to either the boiling point or the ambient temperature. However, this approximation is unacceptable at 1 atm. Among the three flame-sheet models, the one using non-equilibrium evaporation at the surface and individual molecular weights best approximates the finite reaction rate theory. However, this agreement breaks down for smaller droplets with lower surface temperatures, or for air with a larger oxygen content. These conclusions are independent of the chosen kinetics. The Clausius-Clapeyron approximation is shown to be excellent away from the boiling point for $R = 10^{-2}$ cm. However, as the droplet surface temperature approaches the boiling point, or the droplet radius decreases, this assumption leads to considerable errors in the evaporation rate and also distortion of the thermal layer. Even larger errors are obtained when an average molecular weight is used. Here, large underestimates of the evaporation rate and great distortions of the thermal layer of the droplet are obtained. In spite of these errors, all four models agree at wet-bulb conditions.

Based on work performed under Contract N00014-75-C-0705 issued by the Office of Naval Research.

"NITRAMINE FLAME CHEMISTRY AND DEFLAGRATION INTERPRETED IN TERMS OF A FLAME MODEL"

M. Ben Reuven and L. H. Caveny

AIAA Paper 79-1133, AIAA 15th Propulsion Conference, June 1979

The diversity of chemical kinetic time scales associated with nitramine decomposition has led to incorporation of two simultaneous overall reactions in the vapor phase model of deflagration. This allowed derivation of an asymptotic burning rate formula, showing variable pressure dependence. The comprehensive model considers a reacting melt layer, coupled to the gas field through conservation conditions satisfied by all chemical species and enthalpy, is solved numerically; the initial version was presented in Proceedings of 16th Combustion Symposium, 1976. The structure of the deflagration wave near the propellant surface is obtained, along with the overall pressure dependence of the surface temperature and the flame speed eigenvalue, comparing RDX and HMX. A mechanism of coupling between secondary reactions and heat feedback to the surface is proposed, and a quantitative measure of the effect of condensed phase exothermicity on burning rate is demonstrated.

Based on research sponsored by the Power Branch of the Office of Naval Research and supplemented by Army Research Office under Contract N00014-75-C-0705.

"EROSIVE BURNING THEORY FOR PROPELLANTS WITH EXTENDED FLAME ZONES"

M. Ben Reuven and L. H. Caveny

AIAA Paper 80-0142 AIAA 18th Aerospace Sciences Meeting, January 1980.

Propellants containing large amounts of nitramines experience burning rate increases under rocket motor cross-flow conditions. Such propellants have relatively low burning rates and thick flame zones, which make them susceptible to velocity coupling. A simplified theory is advanced, postulating two thermodynamic coupling criteria between the coreflow and the extended gaseous flame zone. Calculated results reveal that coupling between the core and the far field in the flame, which involves only a few percent unreactedness, may result in appreciable burning rate modification. Increases of pressure and port diameter tend to decrease the extent of burning rate enhancement and increase the threshold mass flux in the core. Increasing axial length has the opposite effect.

Based on research sponsored by the Power Branch of the Office of Naval Research and supplemented by the Army Ballistic Research Laboratory under Contract N00014-75-C-0705.

"DIRECT MEASUREMENTS OF ACOUSTIC ADMITTANCE"

Leonard H. Caveny, S. W. Cheng and W. A. Sirignano

Proceedings of 16th JANNAF Combustion Meeting CPIA Publ. 308, Vol. II, pp. 343-361, Dec. 1979; submitted to AIAA Journal.

Research was directed at making measurements of velocities in propane/air and solid propellant flames using laser Doppler velocimetry (LDV) instrumentation. Combustors were developed to impose a controlled periodic pressure disturbance on burning solid propellants and to excite a propane/air flame. A tracking system was developed to maintain the LDV control volume at a fixed position above the regressing propellant surface. The research demonstrated that unsteady velocities (up to 1000 Hz) could be measured for specific double base and composite propellants and for alumina seeded propane/air flames. The simultaneous velocity and pressure measurements were used to obtain acoustic admittances.

Based on research sponsored by the Power Branch of the Office of Naval Research and supplemented by the Army Ballistic Research Laboratory under Contract N00014-75-C-0705.

"NITRAMINE MONOPROPELLANT DEFLAGRATION AND GENERAL NONSTEADY REACTING ROCKET CHAMBER FLOWS"

M. Ben Reuven and L. H. Caveny

Mechanical and Aerospace Engineering Report 1455, Princeton University, Princeton, NJ January 1980.

A theoretical investigation is presented on the deflagration of cyclic nitramines (e.g., RDX and HMX), which are considered as highly-energetic components in solid propellant formulations for rocket motors. The first part of the study involves a steady state deflagration analysis of these monopropellants. This serves as a necessary preliminary step in the elucidation of these compounds within a propellant matrix. The analysis in the second part is aimed at the behavior of nitramine-like propellants within an interior burning propellant grain. This was prompted by the notion of thick overall gaseous flame zone associated with nitramine compounds at pressures up to 5 MPa. The analysis revealed that relatively small deviations from fully-burnt state at the wall layer edge may be associated with appreciable burning rate perturbations. The problem of dynamic coupling between the axial acoustic field and the pressure-sensitive residual reaction in the core was addressed. A comparison of chemical relaxation (secondary reaction) and fluid-dynamic timescales indicates possible areas of Rayleigh-type coupling. This analysis points to the existence of an additional component to acoustic instability, namely, an acoustic coupling with heat addition by residual reaction in the core.

Based on research sponsored by the Power Branch of the Office of Naval Research and supplemented by the Army Ballistic Research Laboratory under Contract N00014-75-C-0705.

"UNSTEADY REACTING FLOWS IN SOLID ROCKET CHAMBERS"

M. Ben Reuven and L. H. Caveny

AIAA Paper 80-1125, AIAA 16th Propulsion Conference, June 1980.

Residual exothermic reactions within the core-flow of interior-burning motor grains can result when propellants containing large amounts of nitramines (RDX, HMX) are utilized. These propellants tend to burn with thick flame zones, which may extend beyond the wall-layer region. The stationary aspects of core/wall-layer interaction for such motor configurations have been investigated previously, leading to an erosive burning theory. The present analysis addresses the problem of dynamic coupling between the axial acoustic field and the pressure-sensitive residual core exothermicity. Comparison between timescales for chemical relaxation and acoustics indicate possible areas for Rayleigh-type coupling. In a finite-difference solution of the nonsteady, one dimensional core flowfield, along with a quasi steady wall-layer, such dynamic coupling has been demonstrated, in the form of spontaneous evolution of acoustic oscillations with slowly-increasing amplitude. In cases of vanishing core/wall-layer interaction, such instability does not evolve. The effects of mean pressure, overall kinetics constant, extent of fuel/oxidizer nonstoichiometry and turbulence intensity for heat feedback to the wall-layer have been investigated in a parametric study. The existence of an additional component to acoustic instability is therefore pointed out this phenomenon must be studied within the realm of the particular chamber configuration, since it combines propellant properties with the flowfield in a non-linear manner.

Based on research sponsored by the Power Branch of the Office of Naval Research and supplemented by the Army Ballistic Research Laboratory under Contract N00014-75-C-0705.

ENERGETIC MATERIALS RESEARCH

DISTRIBUTION LIST

	No. Copies
Assistant Secretary of the Navy (R, E, and S) Attn: Dr. R.E. Reichenbach Room 5E787 Pentagon Washington, DC 20350	1
Office of Naval Research Code 473 Arlington, VA 22217 Attn: Dr. R. Miller	10
Office of Naval Research Code 200B Arlington, VA 22217 Attn: Dr. J. Enig	1
Office of Naval Research Code 260 Arlingon, VA 22217 Attn: Mr. D. Siegel	1
Office of Naval Research Western Office 1030 East Green Street Pasadena, CA 91106 Attn: Dr. T. Hall	1
Office of Naval Research Eastern Central Regional Office 495 Summer Street Boston, MA 02210 Attn: Dr. L. Peebles Dr. A. Wood	2
Office of Naval Research San Francisco Area Office One Hallidie Plaza Suite 601 San Francisco, CA 94102 Attn: Dr. P. A. Miller	1
Defense Technical Information Center DTIC-DDA-2 Cameron Station Alexandria, VA 22314	12

	No. Copies
AFATL Eglin AFB, FL 32542 Attn: Dr. Otto K. Heiney	1
AFRPL Code PACC Edwards AFB, CA 93523 Attn: Mr. W. C. Andrepont	1
AFRPL Code CA Edwards AFB, CA 93523 Attn: Dr. R. R. Weiss	1
Code AFRPL MKPA Edwards AFB, CA 93523 Attn: Mr. R. Geisler	1
Code AFRPL MKPA Edwards AFB, CA 93523 Attn: Dr. F. Roberto	1
AFSC Andrews AFB, Code DLFP Washington, DC 20334 Attn: Mr. Richard Smith	1
Air Force Office of Scientific Research Directorate of Chemical & Atmospheric Sciences Bolling Air Force Base Washington, DC 20332	1
Air Force Office of Scientific Research Directorate of Aero-space Sciences Bolling Air Force Base Washington, DC 20332 Attn: Dr. L. H. Caveny	1
Anal-Syn Lab Inc. P.O. Box 547 Paoli, PA 19301 Attn: Dr. V. J. Keenan	1

	No. Copies
Army Ballistic Research Labs Code DRDAR-BLP Aberdeen Proving Ground, MD 21005 Attn: Mr. L. A. Watermeier	1
Army Ballistic Research Labs ARRADCOM Code DRDAR-BLP Aberdeen Proving Ground, MD 21005 Attn: Dr. Ingo W. May	1
Army Ballistic Research Labs ARRADCOM Code DRDAR-BLT Aberdeen Proving Ground, MD 21005 Attn: Dr. Philip Howe	1
Army Missile Command Code DRSME-RK Redstone Arsenal, AL 35809 Attn: Dr. R. G. Rhoades Dr. W. W. Wharton	2
Atlantic Research Corp. 5390 Cherokee Avenue Alexandria, VA 22314 Attn: Dr. C. B. Henderson	1
Ballistic Missile Defense Advanced Technology Center P.O. Box 1500 Huntsville, AL 35807 Attn: Dr. David C. Sayles	1
Ballistic Research Laboratory USA ARRADCOM DRDAR-BLP Aberdeen Proving Ground, MD 21005 Attn: Dr. A. W. Barrows	1
Hercules Inc. Cumberland Aerospace Division Allegany Ballistics Lab P.O. Box 210 Cumberland, MD 21502 Attn: Dr. Rocco Musso	2

	No. Copies
Hercules Inc. Eglin AFATL/DLDL Eglin AFB, FL 32542 Attn: Dr. Ronald L. Simmons	1
Hercules Inc. Magna Bacchus Works P.O. Box 98 Magna, UT 84044 Attn: Mr. E. H. DeButts	1
Hercules Inc. Magna Bacchus Works P.O. Box 98 Magna, UT 84044 Attn: Dr. James H. Thacher	1
HQ US Army Material Development Readiness Command Code DRCDE-DW 5011 Eisenhower Avenue Room 8N42 Alexandria, VA 22333 Attn: Mr. S. R. Matos	1
Johns Hopkins University APL Chemical Propulsion Information Agency Johns Hopkins Road Laurel, MD 20810 Attn: Mr Theodore M. Gilliland	1
Lawrence Livermore Laboratory University of California Livermore, CA 94550 Attn: Dr. M. Finger	1
Lawrence Livermore Laboratory University of California Livermore, CA 94550 Attn: Dr. R. McGuire	1
Lockheed Missiles and Space Co. P.O. Box 504 Sunnyvale, CA 94088 Attn: Dr. Jack Linsk Org. 83-10 Bldg. 154	1

	No. Copies
Lockheed Missile & Space Co. 3251 Hanover Street Palo Alto, CA 94304 Attn: Dr. H. P. Marshall Dept. 52-35	1
Los Alamos Scientific Lab P.O. Box 1663 Los Alamos, NM 87545 Attn: Dr. R. Rogers, WX-2	1
Los Alamos Scientific Lab P.O. Box 1663 Los Alamos, NM 87545 Attn: Dr. B. Craig, M Division	1
Naval Air Systems Command Code 330 Washington, DC 20360 Attn: Mr. R. Heitkotter Mr. R. Brown	1
Naval Air Systems Command Code 310 Washington, DC 20360 Attn: Dr. H. Mueller Dr. H. Rosenwasser	1
Naval Explosive Ordnance Disposal Facility Indian Head, MD 20640 Attn: Lionel Dickinson Code D	1
Naval Ordnance Station Code 5034 Indian Head, MD 20640 Attn: Mr. S. Mitchell	1
Naval Ordnance Station Code PM4 Indian Head, MD 20640 Attn: Mr. C. L. Adams	1
Dean of Research Naval Postgraduate School Monterey, CA 93940 Attn: Dr. William Tolles	1
Naval Research Lab Code 6510 Washington, DC 20375 Attn: Dr. J. Schnur	1

	No. Copies
Naval Research Lab Code 6100 Washington, DC 20375	1
Naval Sea Systems Command Washington, DC 20362 Attn: Mr. G. Edwards, Code 62R3 Mr. J. Murrin, Code 62R2 Mr. W. Blaine, Code 62R	1
Naval Sea Systems Command Washington, DC 20362 Attn: Mr. R. Beauregard SEA 64E	1
Naval Surface Weapons Center Code R11 White Oak, Silver Spring, MD 20910 Attn: Dr. H. G. Adolph	1
Naval Surface Weapons Center Code R13 White Oak, Silver Spring, MD 20910 Attn: Dr. R. Bernecker	1
Naval Surface Weapons Center Code R10 White Oak, Silver Spring, MD 20910 Attn: Dr. S. J. Jacobs	1
Naval Surface Weapons Center Code R11 White Oak, Silver Spring, MD 20910 Attn: Dr. M. J. Kamlet	1
Naval Surface Weapons Center Code R04 White Oak, Silver Spring, MD 20910 Attn: Dr. D. J. Pastine	1
Naval Surface Weapons Center Code R13 White Oak, Silver Spring, MD 20910 Attn: Dr. E. Zimet	1

	No. Copies
Naval Surface Weapons Center Code R101 Indian Head, MD 20640 Attn: Mr. G. L. MacKenzie	1
Naval Surface Weapons Center Code R17 Indian Head, MD 20640 Attn: Dr. H. Haiss	1
Naval Surface Weapons Center Code R11 White Oak, Silver Spring, MD 20910 Attn: Dr. K. F. Mueller	1
Naval Surface Weapons Center Code R16 Indian Head, MD 20640 Attn: Dr. T. D. Austin	1
Naval Surface Weapons Center Code R122 White Oak, Silver Spring, MD 20910 Attn: Mr. L. Roslund	1
Naval Surface Weapons Center Code R121 White Oak, Silver Spring, MD 20910 Attn: Mr. M. Stosz	1
Naval Weapons Center Code 3853 China Lake, CA 93555 Attn: Dr. R. Atkins	1
Naval Weapons Center Code 3205 China Lake, CA 93555 Attn: Dr. L. Smith	1
Naval Weapons Center Code 3205 China Lake, CA 93555 Attn: Dr. C. Thelen	1
Naval Weapons Center Code 385 China Lake, CA 93555 Attn: Dr. A. Amster	1

	No. Copies
Naval Weapons Center Code 388 China Lake, CA 93555 Attn: D. R. Derr	1
Naval Weapons Center Code 388 China Lake, CA 93555 Attn: Dr. R. Reed Jr.	1
Naval Weapons Center Code 385 China Lake, CA 93555 Attn: Dr. A. Nielsen	1
Naval Weapons Center Code 3858 China Lake, CA 93555 Attn: Mr. E. Martin	1
Naval Weapons Center China Lake, CA 93555 Attn: Mr. R. McCarten	1
Naval Weapons Support Center Code 5042 Crane, Indiana 47522 Attn: Dr. B. Douda	1
Rohm and Haas Company 723-A Arcadia Circle Hunsville, Alabama 35801 Attn: Dr. H. Shuey	1
Strategic Systems Project Office Dept. of the Navy Room 901 Washington, DC 20376 Attn: Dr. J. F. Kincaid	1
Strategic Systems Project Office Dept. of the Navy Room 1048 Washington, DC 20376 Attn: Mr. E. L. Throckmorton Mr. R. Kinert	2
Thiokol Chemical Corp. Brigham City Wasatch Division Brigham City, UT 84302 Attn: Dr. G. Thompson	1

	No. Copies
USA ARRADCOM DRDAR-LCE Dover, NJ 07801 Attn: Dr. R. F. Walker	1
USA ARRADCOM DRDAR-LCE Dover, NJ 07801 Attn: Dr. N. Slagg	1
U.S. Army Research Office Chemistry Division P.O. Box 12211 Research Triangle Park, NC 27709	1

DATE
FILMED

8